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Technology Center 2600

EXHIBIT A

Recognition of Halftone Structures

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Project Review, 1998



Electronic Image Fingerprint

- A user model
 - » Image halftoning with multiple screens
 - Start with a “small” set of micro screens
 - Compose halftone screens in terms of micro screens
 - Arbitrary choices of micro screens
 - Perceptually seamless across the boundaries of micro screens

Electronic Image Fingerprint

- An example
 - » Two 32x32 micro screens
 - » A 256x256 composite halftone screen
 - with tile map:
 - » Printed 300dpi
 - » Scanned 600dpi

0	0	0	0	0	1	0	1
1	0	1	1	1	1	1	0
0	1	1	1	1	0	1	0
1	1	1	0	1	1	0	0
1	0	1	0	1	1	0	1
0	0	0	1	0	1	0	1
1	1	0	1	0	0	1	1
1	1	1	1	1	1	0	1



Original Grayscale Image

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Halftone Image
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Scanned Image

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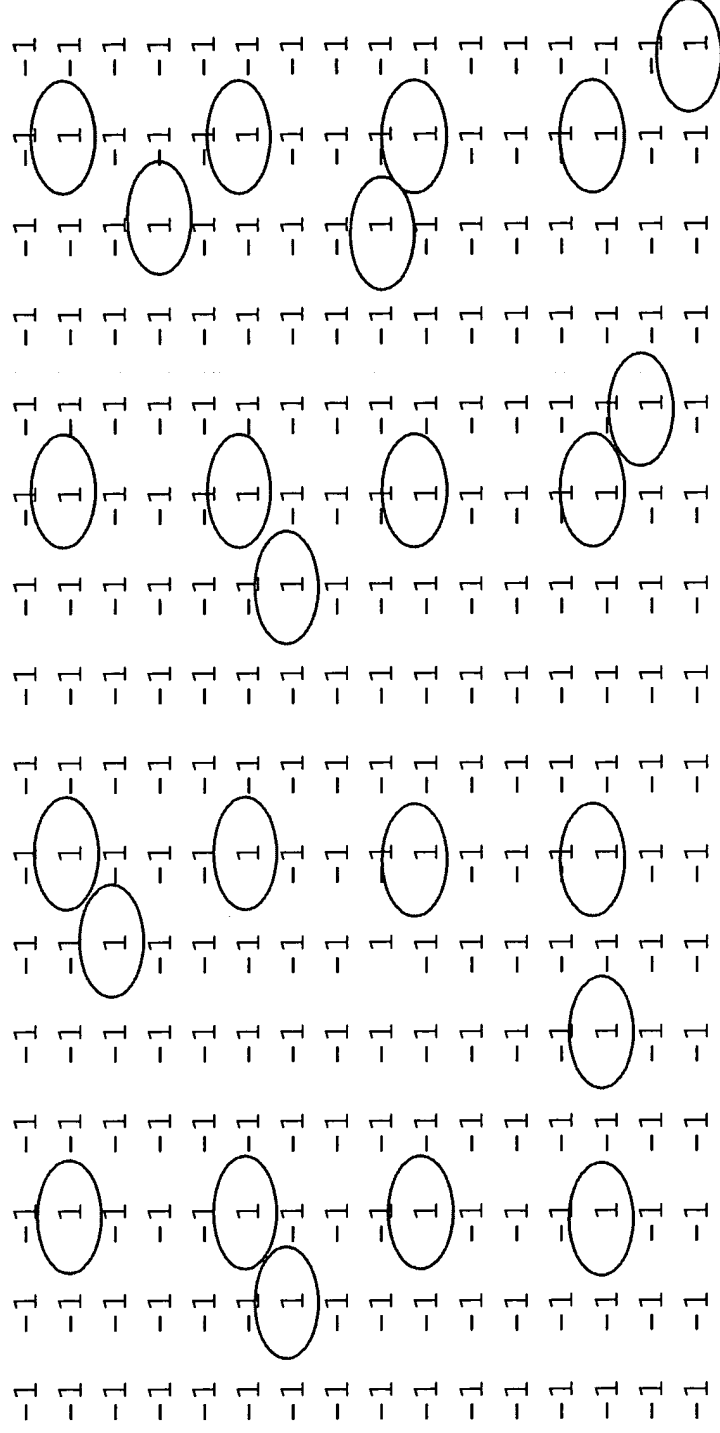
Recognition of Halftone Structures

- Approaches
 - » Matched Filter
 - One (bi-level) match filter per micro screen
 - Construct according to an image intensity level

A 16x16 CSD Halftone Screen

152	84	227	111	187	216	85	203	178	45	191	112	217	44	104	69
210	32	249	2	134	51	244	10	128	229	251	55	174	155	246	26
173	126	65	161	23	235	106	59	147	81	18	140	86	5	197	135
12	99	220	199	90	143	190	165	28	221	118	206	63	233	109	74
192	144	54	176	120	31	70	209	100	184	39	164	129	181	33	223
122	30	240	8	77	224	254	3	151	57	243	9	97	49	253	168
68	239	95	207	137	158	48	93	130	237	75	193	218	154	17	82
159	22	167	107	41	182	113	198	170	35	116	139	61	91	132	200
114	215	58	194	14	232	67	20	214	83	183	25	204	234	42	179
1	76	250	127	150	87	247	123	142	6	248	103	169	13	245	110
188	228	29	98	53	219	36	166	62	230	156	43	141	79	56	148
47	138	163	180	205	4	186	101	202	50	89	212	121	226	195	92
211	88	11	72	117	153	80	136	24	119	189	19	64	177	7	125
34	222	242	131	236	46	252	225	73	171	241	157	38	102	255	162
115	172	60	21	196	105	16	160	213	1	94	238	133	208	78	27
52	201	96	146	37	175	66	124	40	108	149	71	15	185	145	231

A Matched Filter for 16x16 CSD Screen

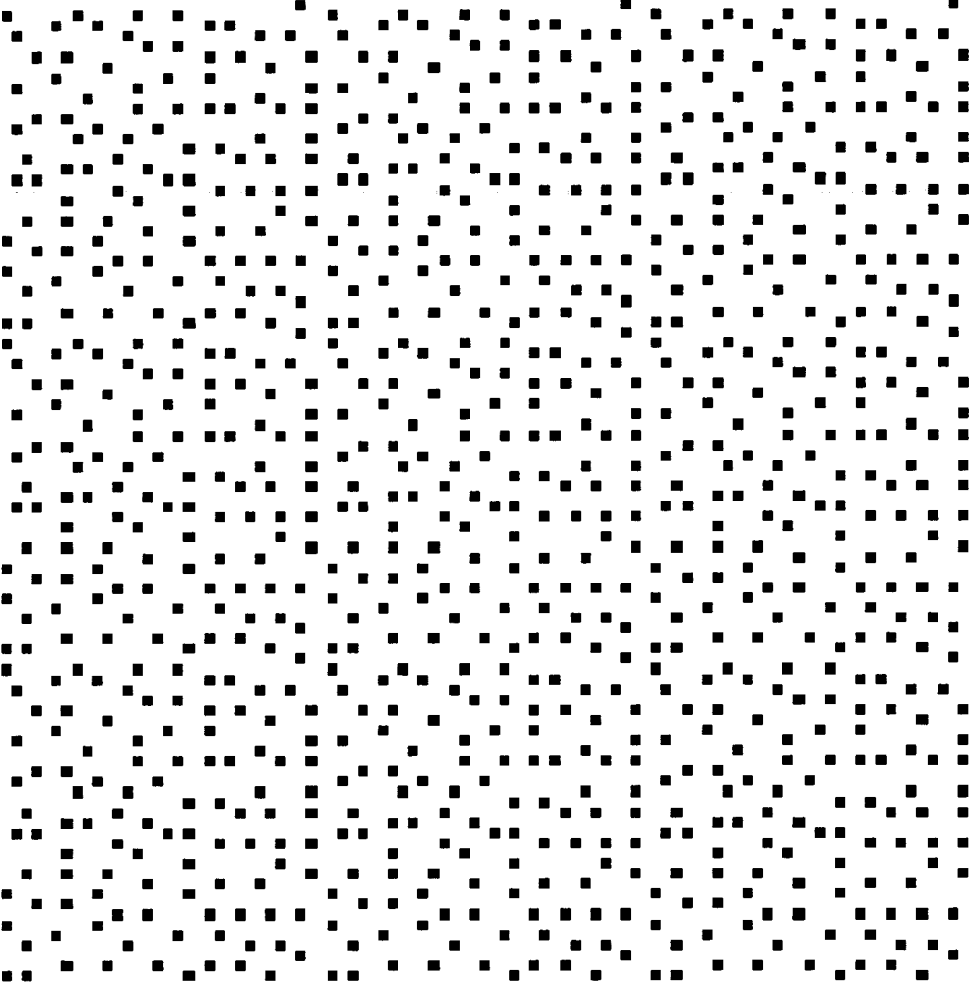


Recognition of Halftone Structures

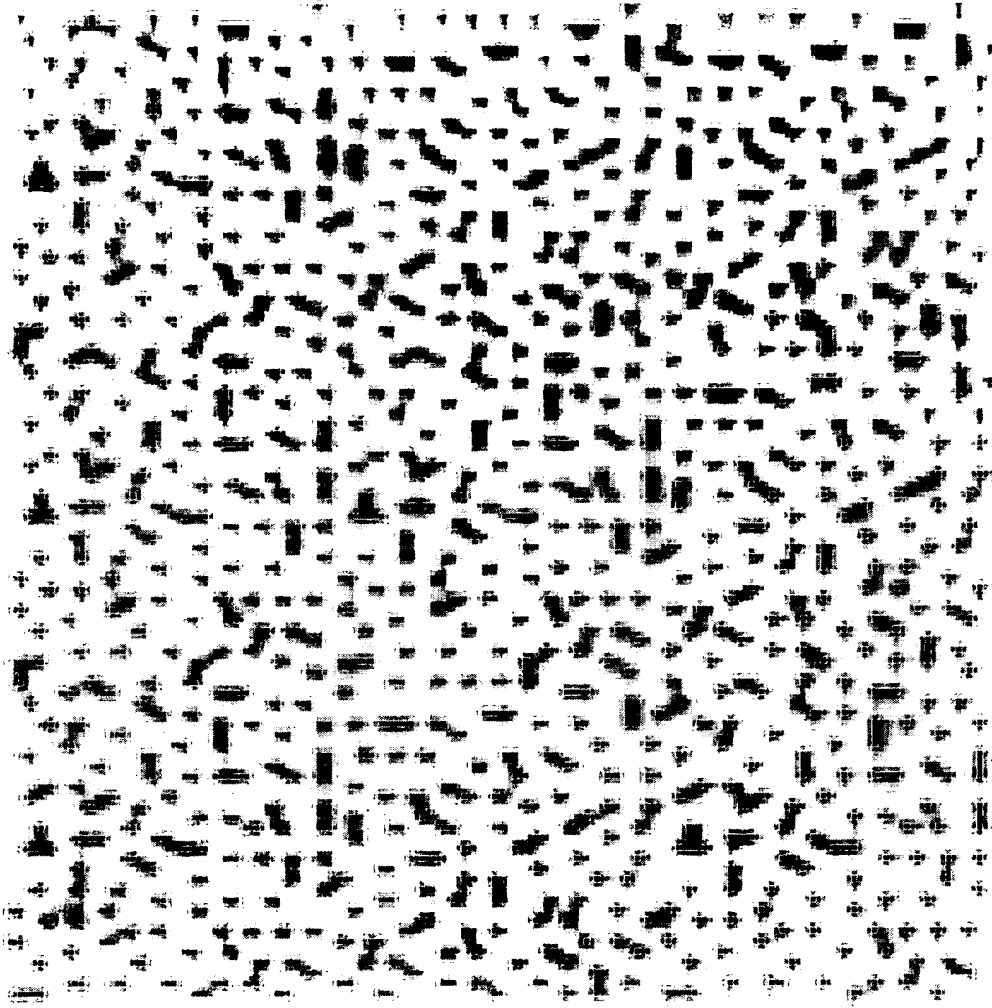
- Approaches
 - » Matched Filter
 - One (bi-level) matched filter per micro screen
 - Construct according to an image intensity level
 - Convolve with the scanned image, per pixel
 - Sharpen the result by a sharpening filter
 - Look for a local maximum
 - Normalize and scale for visualization

A Grayscale (256-level, 10% Darkness) Image

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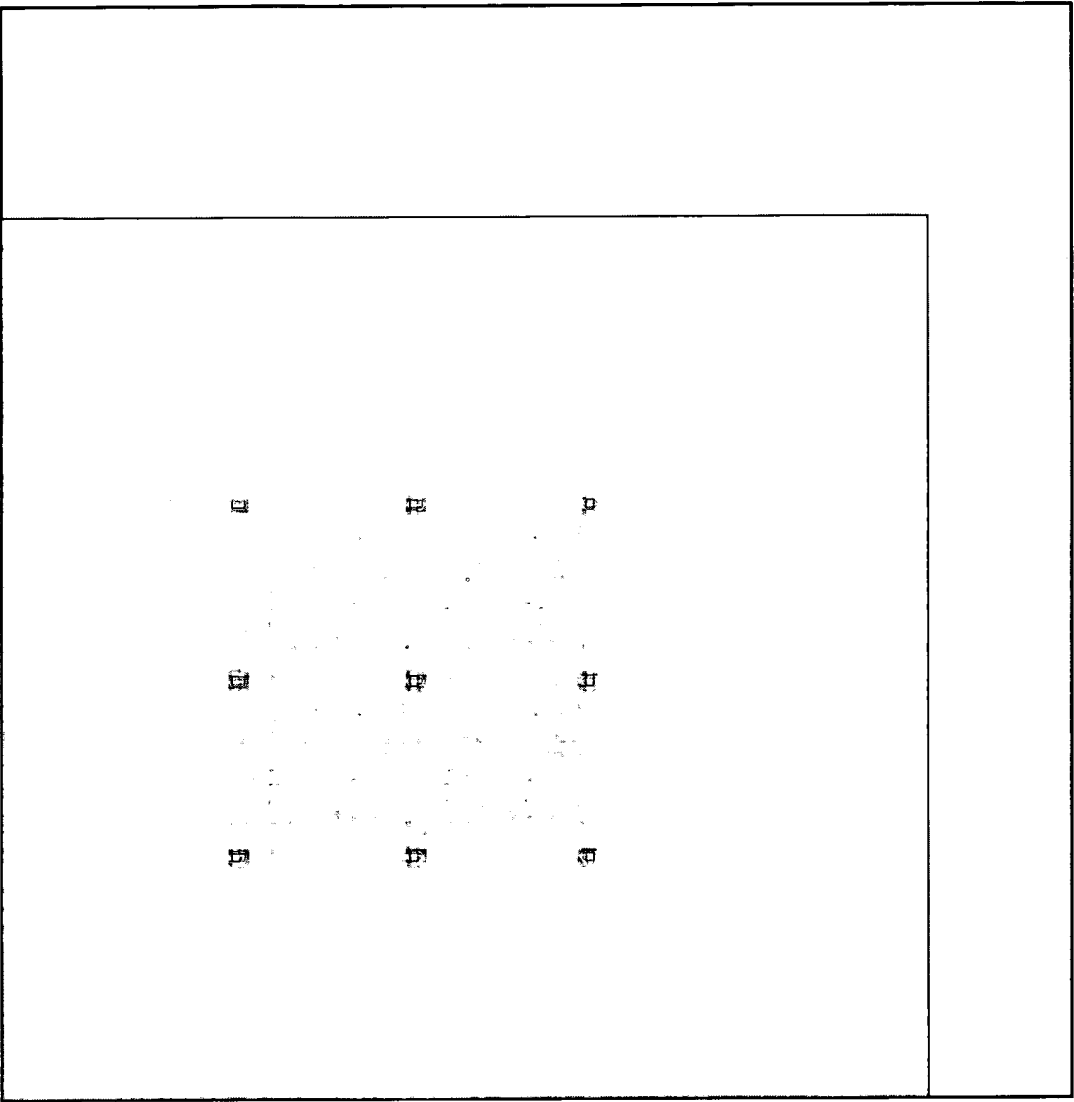


A Halftone (with a 32x32 Screen) Image

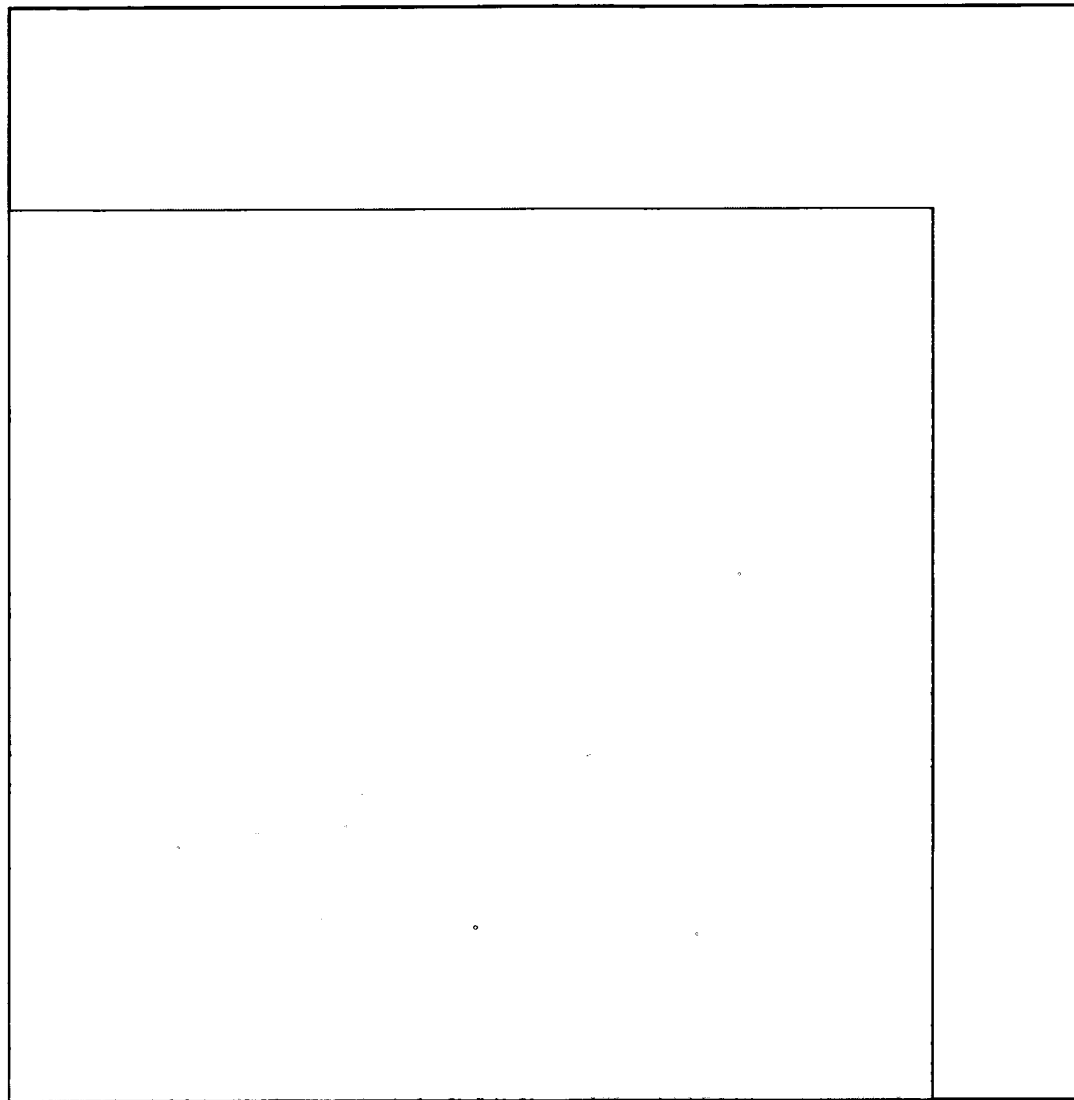


A Scanned Image

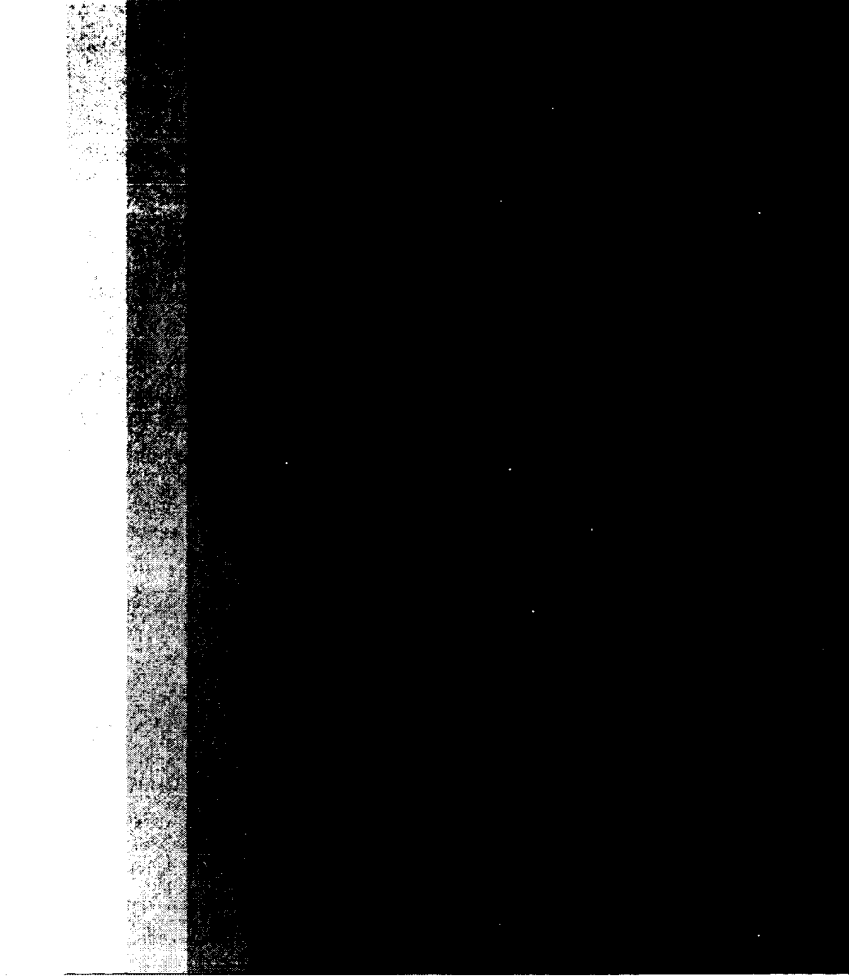
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A Score Map (w.r.t. Screen 1)

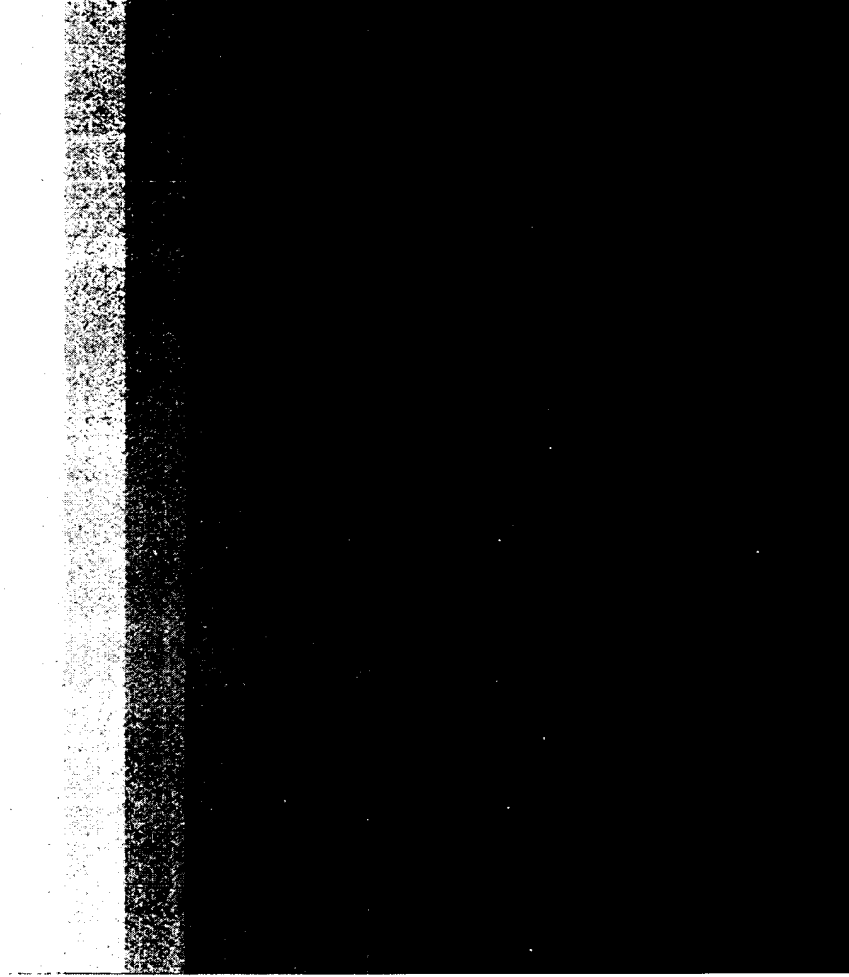


Another Score Map (w.r.t. Screen 2)



A Gray Ramp

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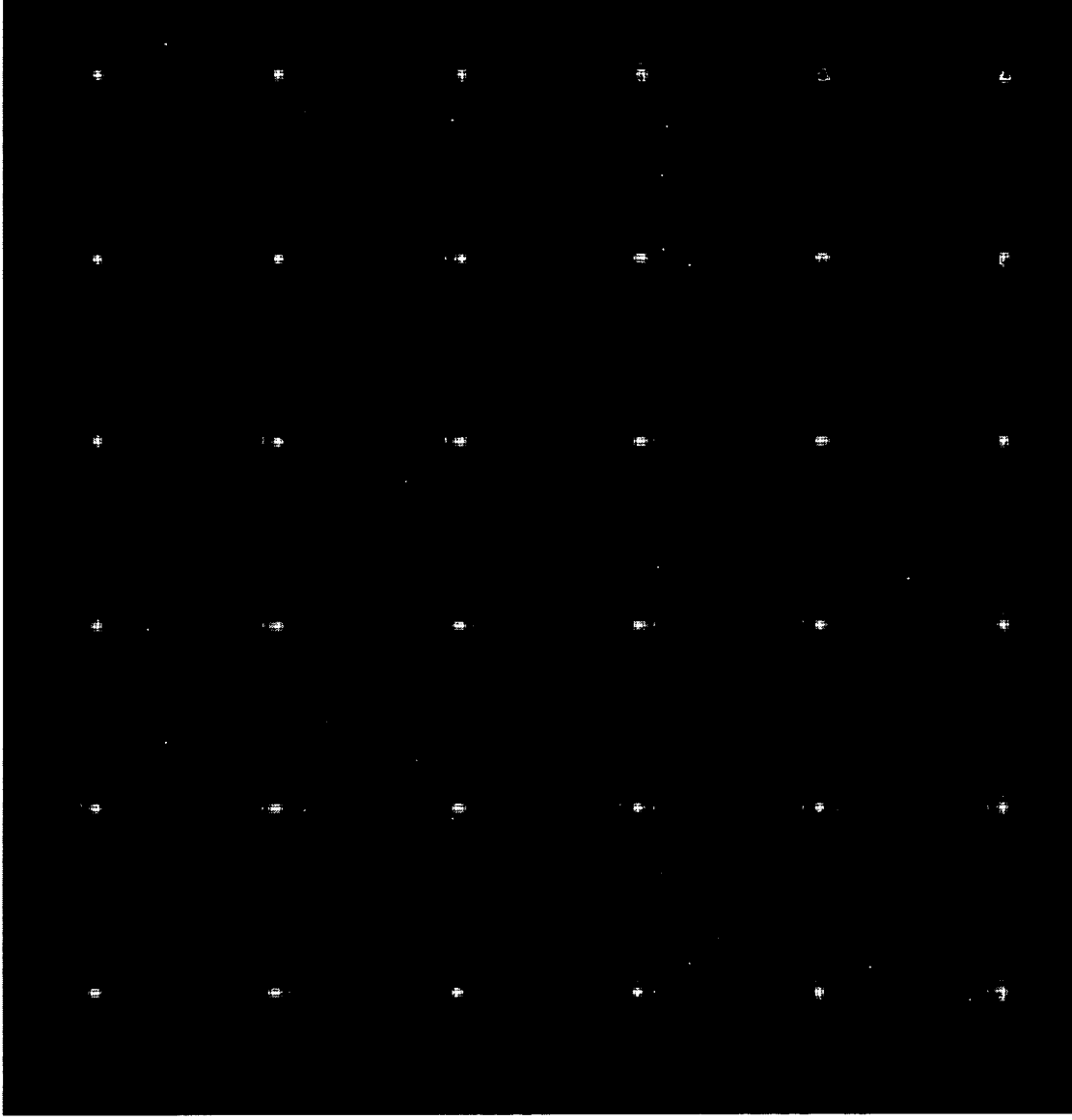
A Half-tone Gray Ramp

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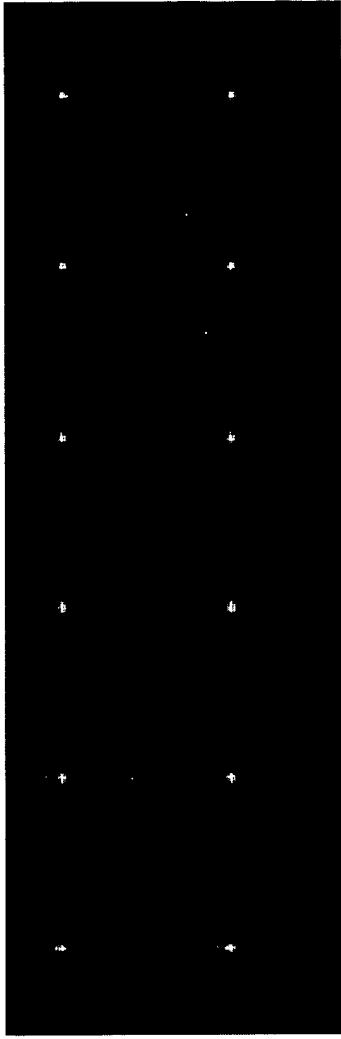


A Scanned Gray Ramp

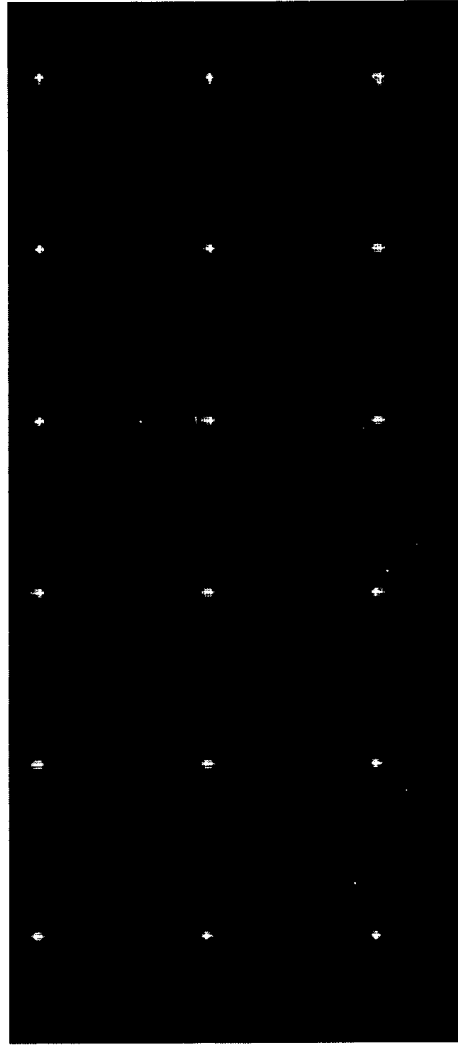
BEST AVAILABLE COPY



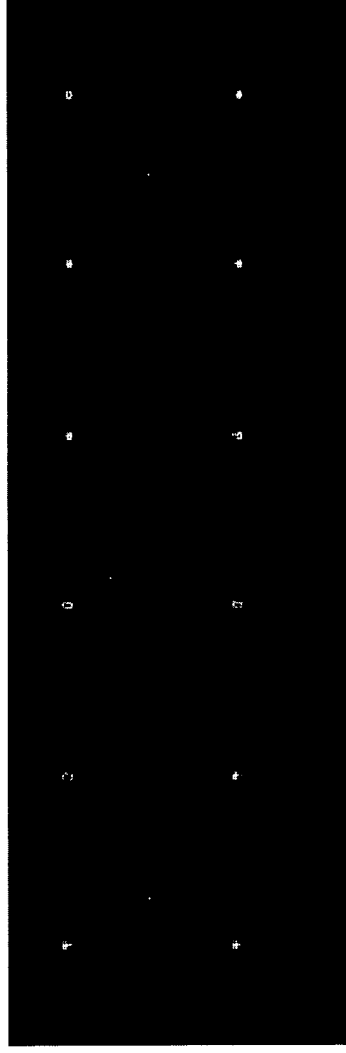
A Portion of Score Map (w.r.t. Screen 1)



25%



50%



75%

Portions of Score Map (w.r.t. Screen 1)

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Recognition of Halftone Structures

- Approaches

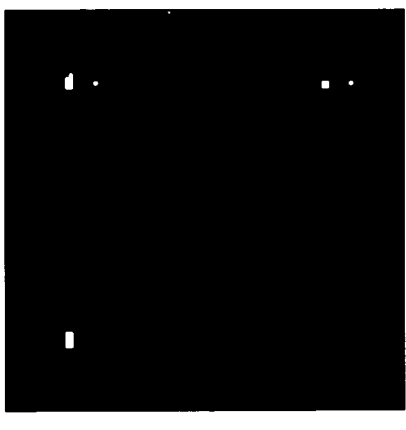
- » Matched Filter

- One (bi-level) matched filter per micro screen
 - Construct according to intensity level 50%
 - Sharpen the filter by a sharpening filter
 - Convolve with the scanned image, per pixel
 - Look for a local maximum by a threshold

0	-1	0
-1	4	-1
0	-1	0

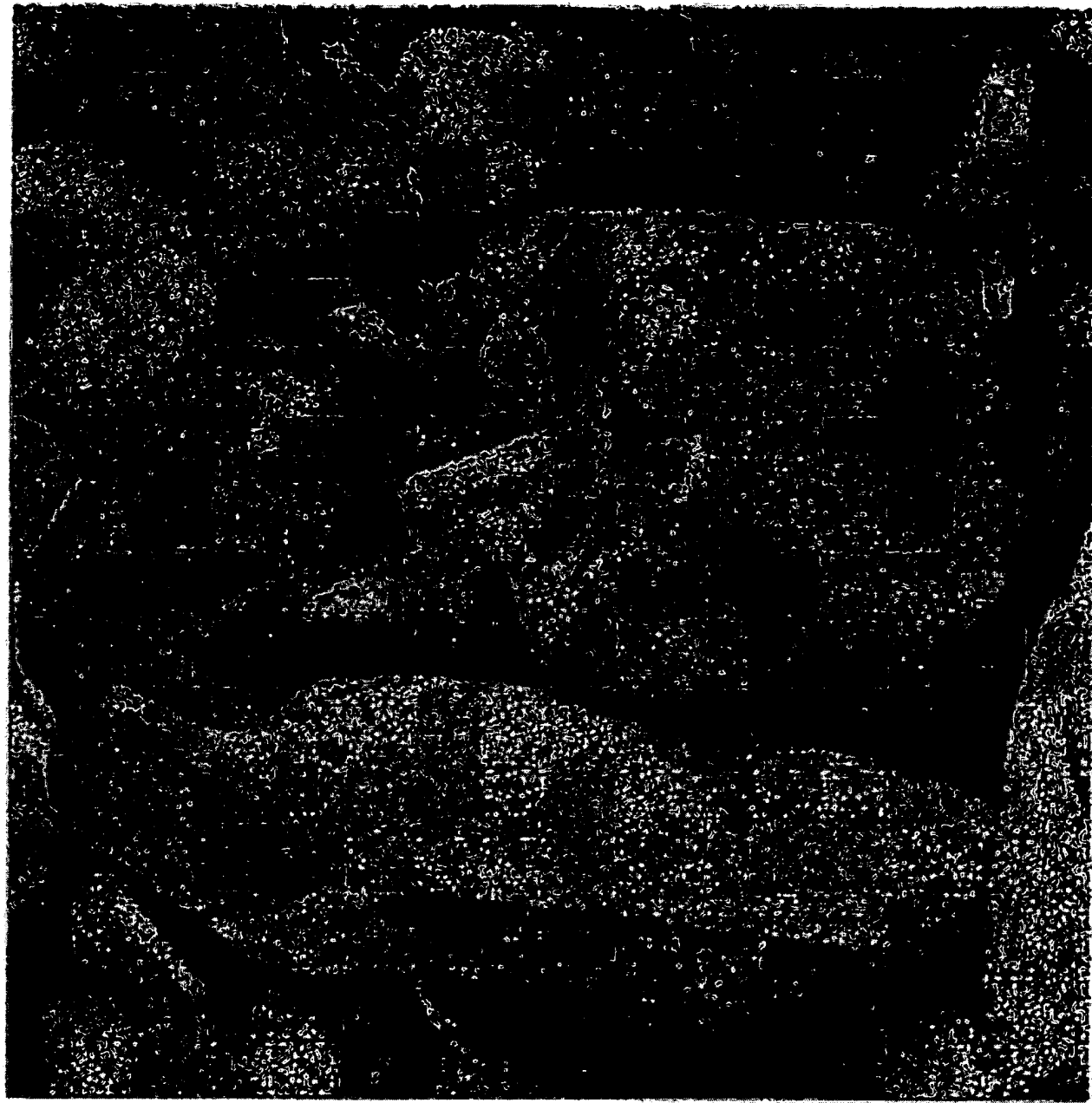
Recognition of Halftone Structures

- Approaches
 - » Global Stitching
 - One score map per micro screen
 - Collect and consolidate pinnacles
 - Tally for coordinates mod screen dimensions
 - Coalesce neighbors
 - Remove outliers
 - Record preliminary results
 - Display color-coded preliminary results



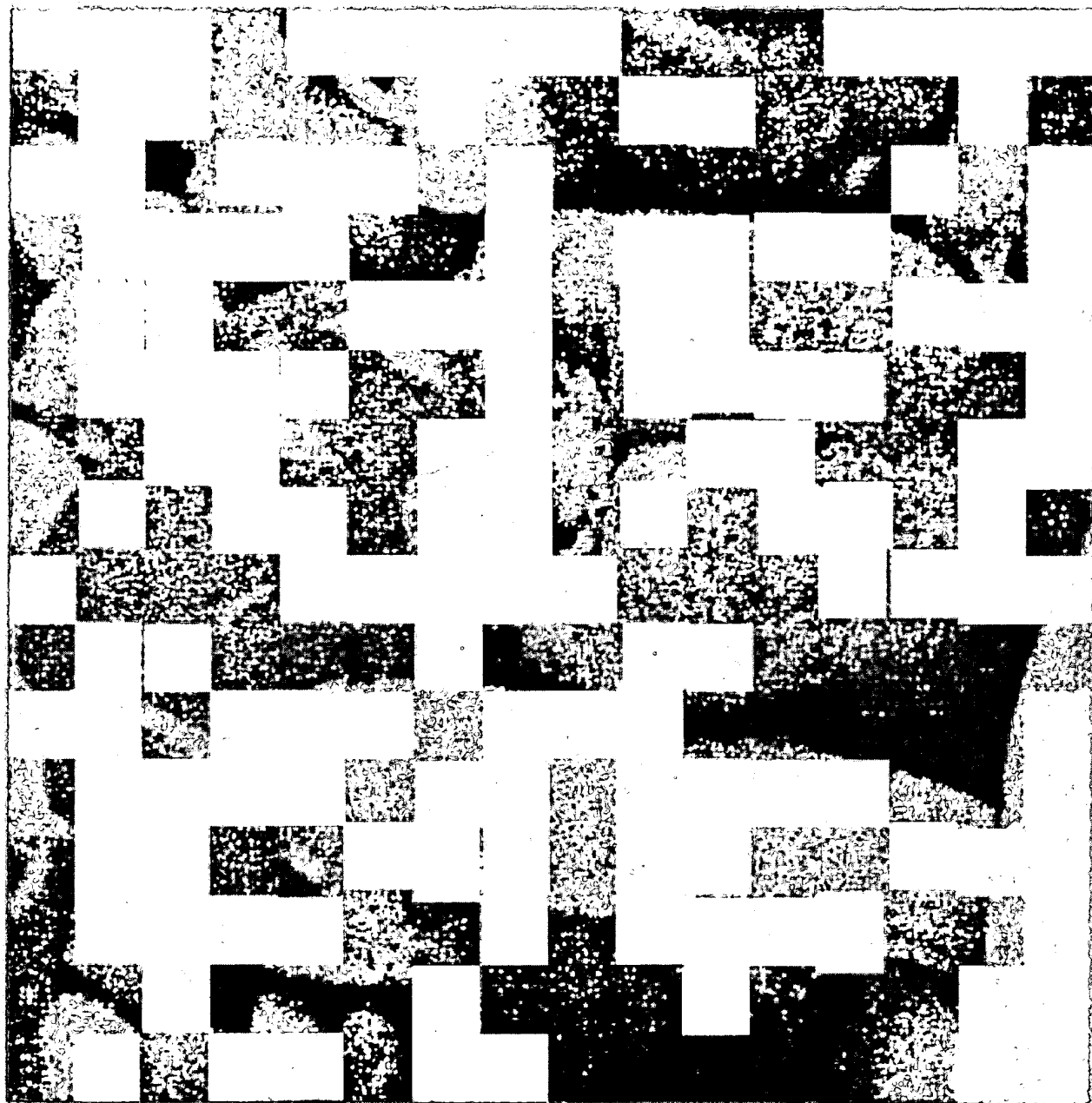


A Scanned Image
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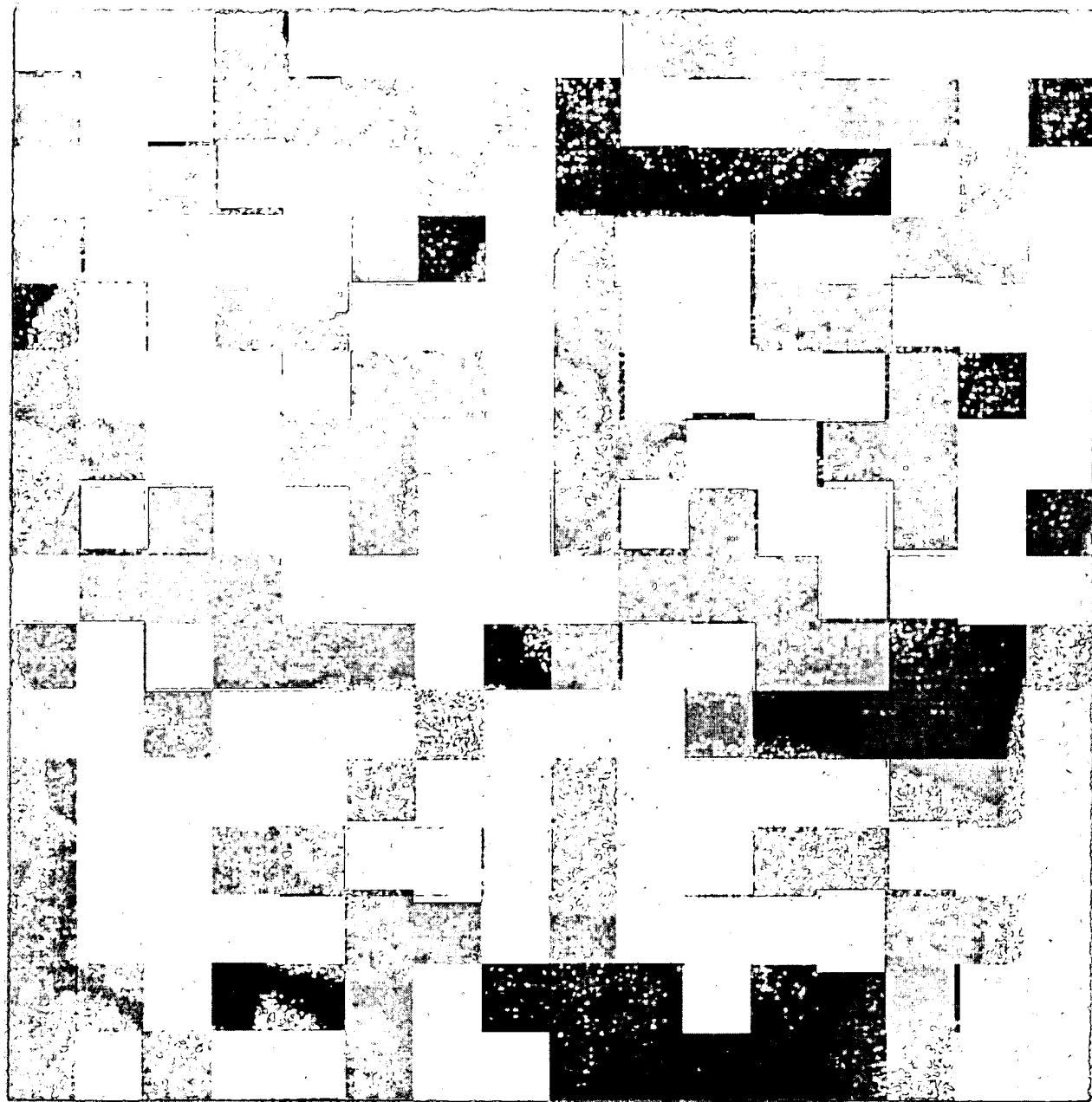
Color-coded Display for Detection of Screen 1

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Color-coded Display for Detection of Screen 2

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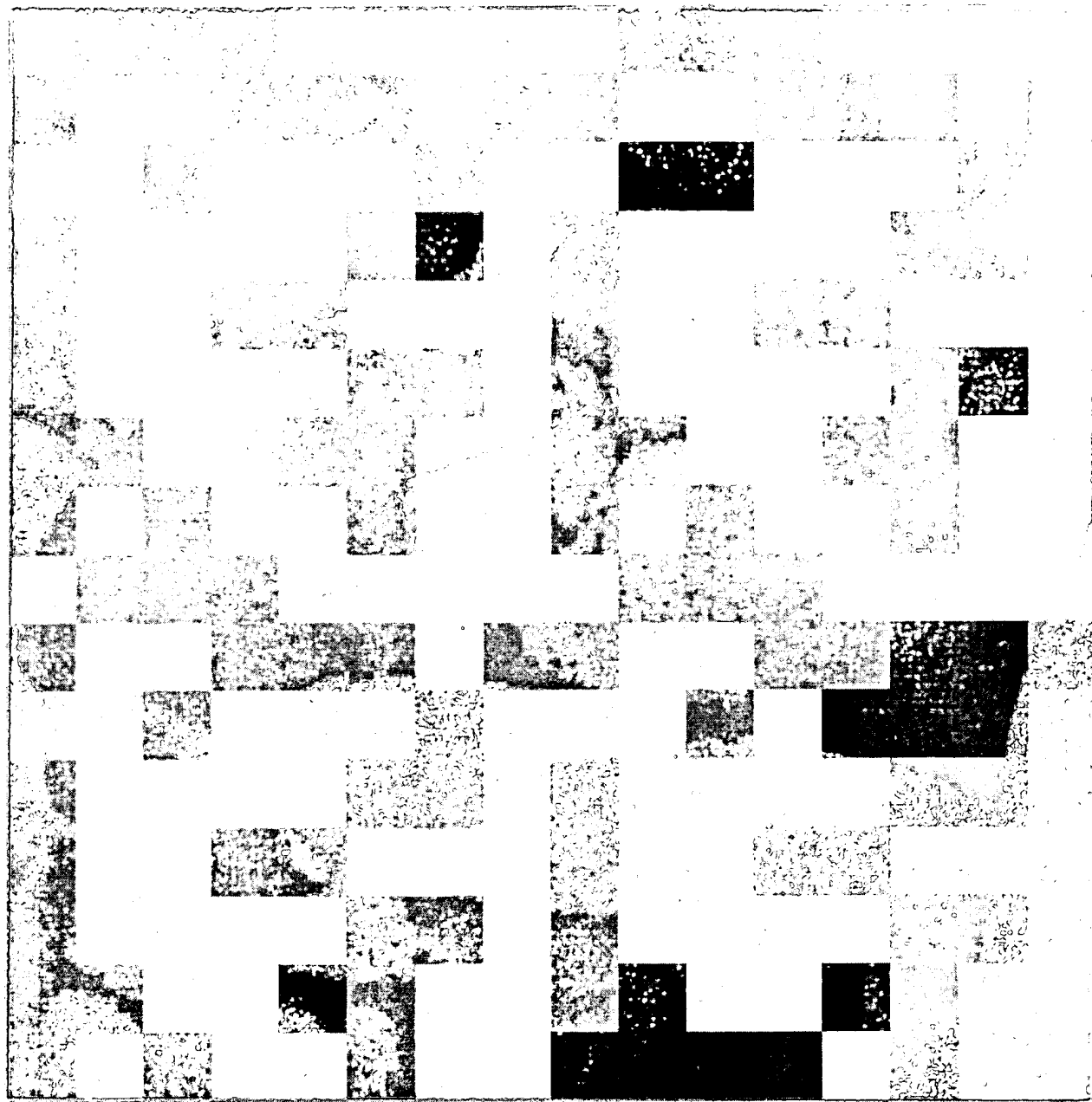
Slide
26/33

Color-coded Display of Preliminary Results

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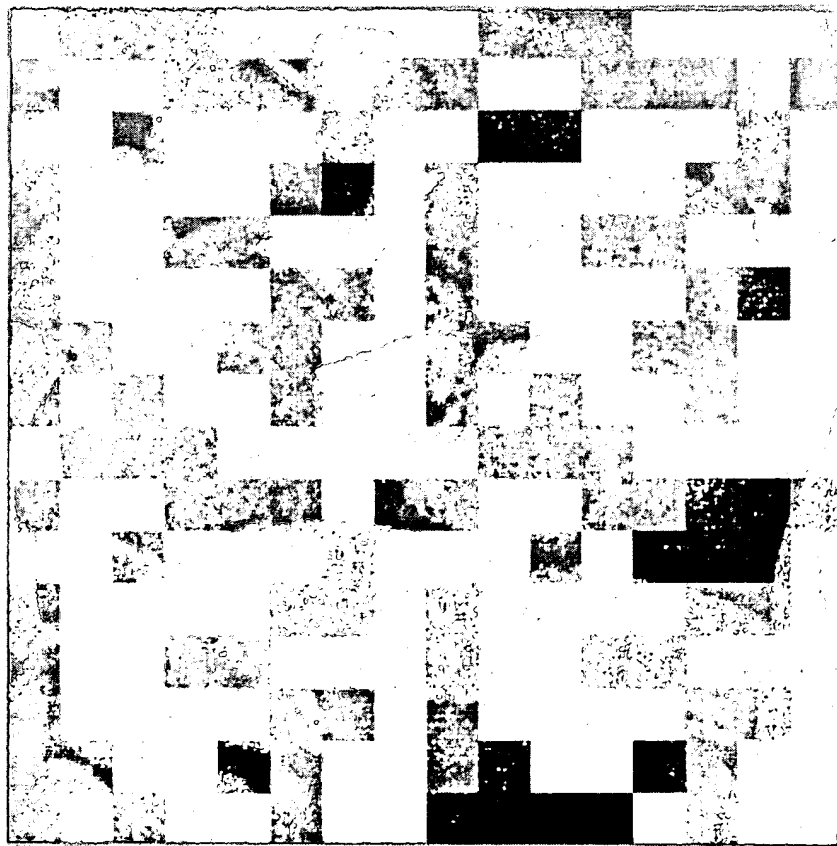
Recognition of Halftone Structures

- Approaches
 - » Global Stitching
 - Resolve ambiguities
 - False alarm (Overlap in score maps)
 - » Compare convolution results
 - » Must differ by a certain amount
 - Missed detection (Absence in score maps)
 - » Lower threshold to look for possible pinnacle
 - » Must be higher than certain amount

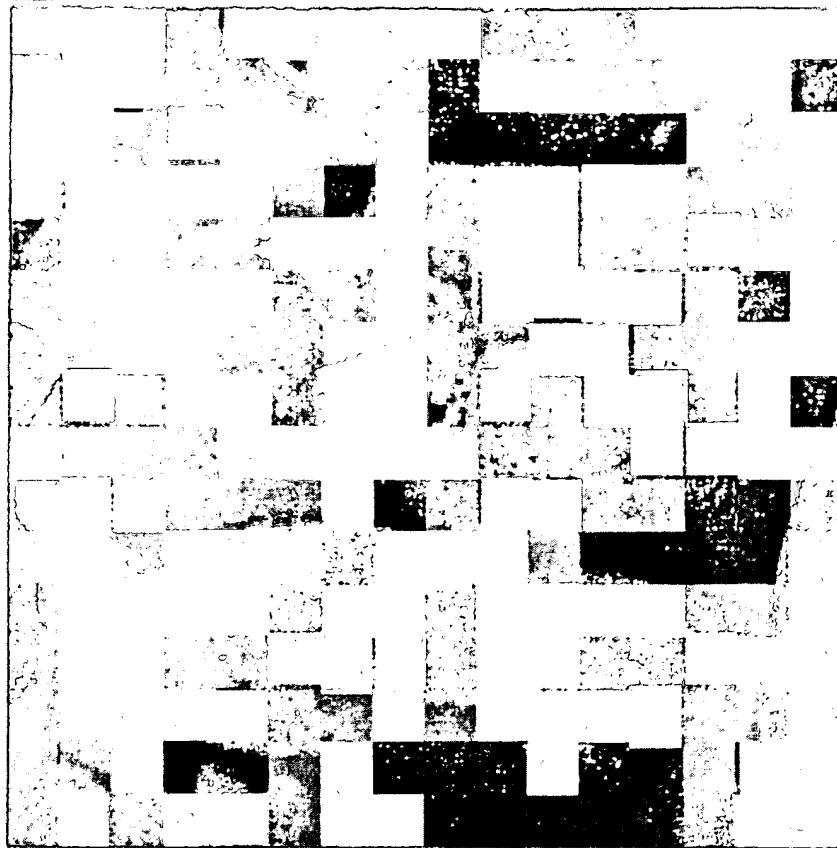


Color-coded Display of Combined Result

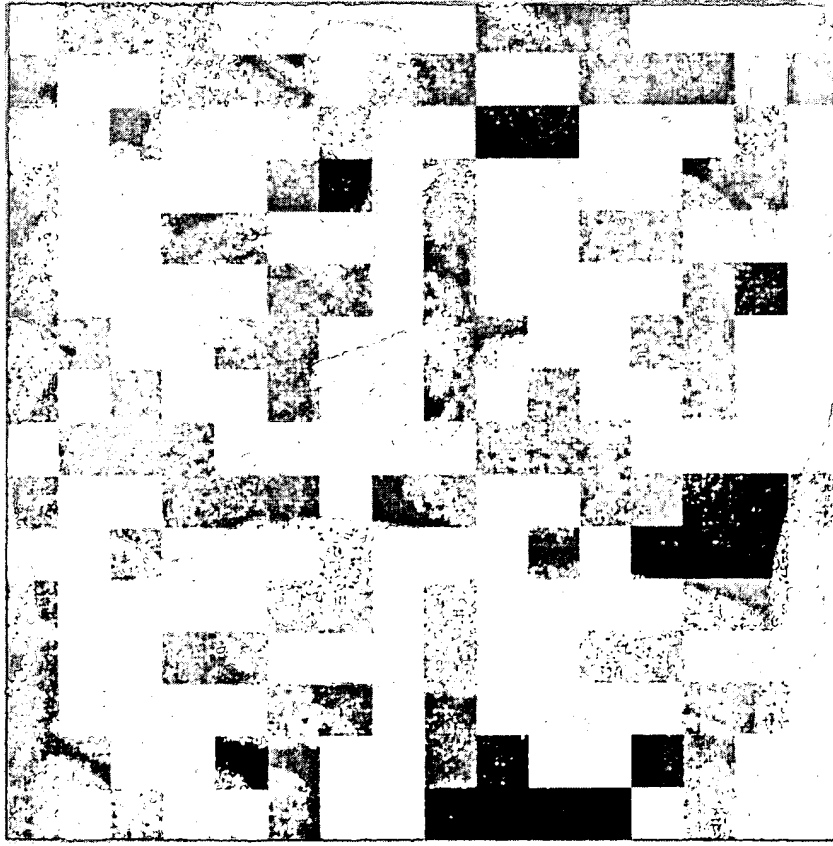
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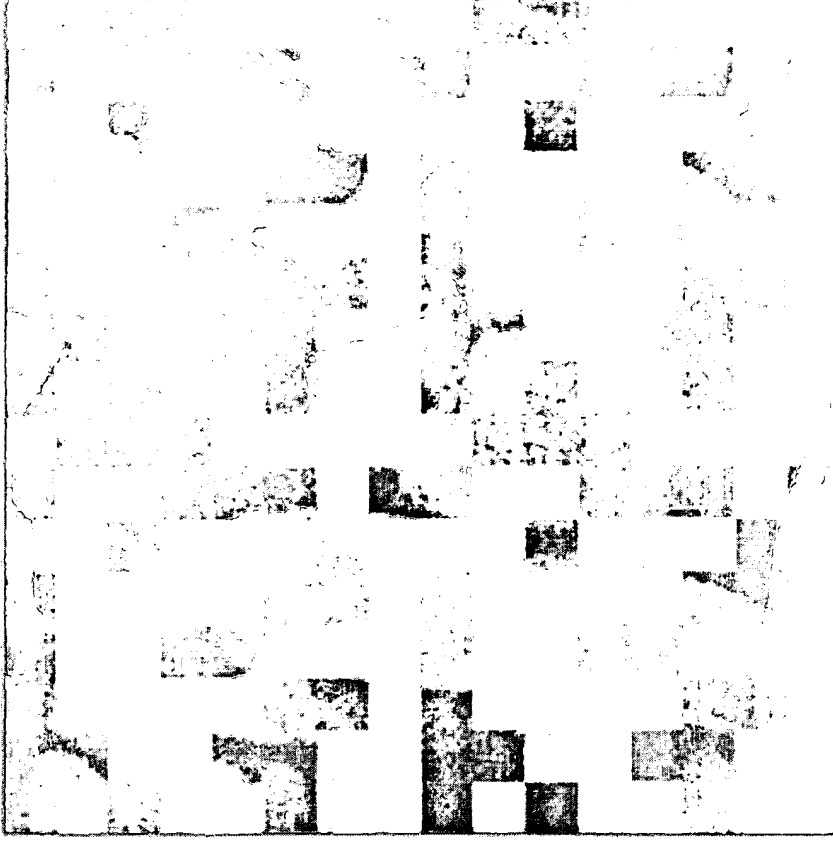
Combined Result



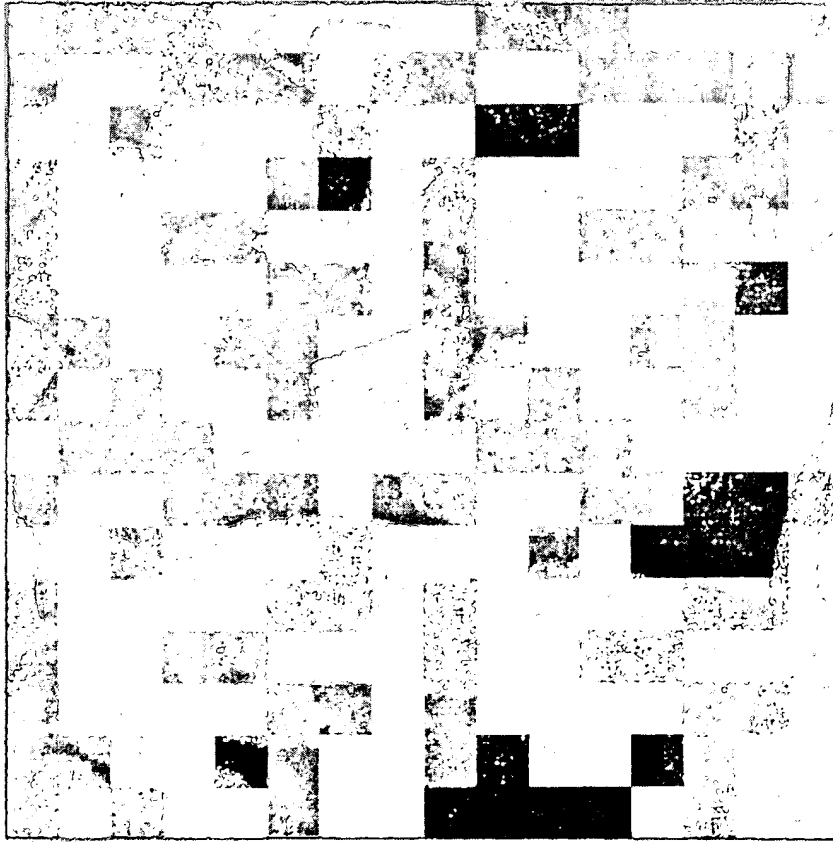
Preliminary Result



Combined Result



Correct Result



Combined Result



Scanned Image

Recognition of Halftone Structures

- Approaches
 - » Global Stitching
 - Resolve ambiguities
 - Record “hard” decisions
 - Resolve uncertainties
 - Adjust intensity level of Matched Filter and repeat
 - Record “soft” decisions
 - Rely on redundancies or error-correction schemes

Summary

- Electronic image fingerprint is feasible, at least for monochrome images, by halftoning the images with micro screens.
- A user model is being defined.
- Match filters are useful for recognition of image halftone structures.
- Must work with up-stream screen designer, encryption encoder as well as down-stream decoder.